A Novel Low-Temperature Diffusion Aluminide Coating for Ultrasupercritical Coal-Fired Boiler Applications

TITLE: **A Novel Low-Temperature Diffusion Aluminide Coating for Ultrasupercritical Coal-Fired Boiler Applications**

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1. ABSTRACT

Program Introduction: Rationale and Objective

Iron aluminide-based coatings have demonstrated excellent oxidation resistance in exhaust/steam environments by forming a protective alumina scale. With the push towards ultra-supercritical steam coal-fired power plants, alumina-forming coatings become particularly attractive because at higher operating temperatures the slow growth of alumina and its stability in the presence of water vapor are superior to coatings that form chromia or silica-rich scales. Conventional processes for fabricating aluminide coatings, such as pack cementation or chemical vapor deposition (CVD), are typically carried out at elevated temperatures (1000-1150°C). Extended thermochemical treatment of the ferritic/martensitic steels at these temperatures could significantly degrade their high-temperature strength and creep resistance. However, when the aluminizing temperature is lowered, brittle Al-rich intermetallic phases tend to form, which will adversely affect the mechanical properties of the coated alloys, particularly the resistance to fatigue cracking. The objective of this research is to develop a coating process via pack cementation for protection of ultra-supercritical boiler internal tubing that will not detrimentally alter the mechanical properties of the coated ferritic/martensitic alloys.

Accomplishments Achieved During the Current Period of Performance

To prevent the formation of the brittle Fe_2Al_5 phase in the coating, the Al activity in the pack cementation process was reduced by substituting the pure Al masteralloy with Cr-Al binary masteralloys containing 25 and 15 wt.% Al. When the Cr-25Al masteralloy was used, a duplex coating was formed on the Fe-9Cr-1Mo substrate alloy after aluminization at 700ºC, consisting of a thin Fe_2Al_5 outer layer and an inner layer of FeAl. With the Cr-15Al masteralloy, the Fe_2Al_5 phase was eliminated and an FeAl coating of ~12 μm was formed. The Al content at the FeAl coating surface was ~50 at.%, as measured by energy dispersive X-ray analysis (EDXA). The effect of the amount of masteralloy on coating growth also was investigated by utilizing packs containing $2NH_4Cl$-x(Cr-15Al)-(98-x)Al_2O_3, where x = 10, 20, 30, 40, 50, 60, and 70 (in wt.%). The results indicate that when the amount of

masteralloy was increased from 10 to 30%, both surface Al content and coating thickness were increased. However, no further increase was observed when the amount of masteralloy was > 40%.

The aluminide coatings fabricated at 700°C using Cr-25Al and Cr-15Al masteralloys are being tested in air + 10% H_2O at 650°C to evaluate their oxidation performance. The coatings synthesized at 1050°C via pack or CVD aluminization were included in the test for comparison. Coated specimens are examined in plan view every 2,000h by scanning electron microscopy (SEM) equipped with EDXA. The low-temperature aluminide coatings have passed 6,000h testing, showing good oxidation protection in humid air.

In addition, with the aim of reducing overall processing time and cost, an initial effort was made to combine the coating process with the standard heat treatment for ferritic/martensitic alloys. A typical heat treatment cycle, including 2h austenization at 1050°C and 2h tempering at 750°C, was employed as the pack aluminizing temperature profile. Both contact and non-contact arrangements were used to compare the surface finish of the coated alloy. The results show that during the heat treatment cycle, a thick aluminide coating (~160 μm) with ~22 at.% Al at the surface was obtained. Most of the coating growth occurred during the first-stage treatment (2h at 1050°C).

Plans for the Remaining Period of Performance

- Continue the oxidation tests in water vapor to evaluate the long-term oxidation performance of the low-temperature aluminide coatings
- Machine and coat the dog-bone specimens and investigate the mechanical properties of the low-temperature aluminide coatings

2. LIST OF PAPER PUBLISHED, CONFERENCE PRESENTATIONS, STUDENTS SUPPORTED UNDER THIS GRANT

- **Publications and Presentations**
  - Y. Q. Wang, "Aluminide Coatings on Fe-9Cr-1Mo Steel Synthesized by Pack Cementation for Power Generation Applications", Ph.D. Dissertation (Chapters 4 and 5), Tennessee Technological University, December 2006.
  - Y. Zhang, Y. Q. Wang, and B. A. Pint, "Evaluation of Iron Aluminide Coatings for Oxidation Protection in Water Vapor Environment", NACE Paper 07-468, Houston, TX, presented at NACE Corrosion 2007, Nashville, TN, March 2007.
  - B. Bates, Y. Zhang, and Y. Q. Wang, "Low-Temperature Aluminide Coatings Synthesized via Pack Cementation on Ferritic/Martensitic Alloys", TMS 2008 Annual Meeting & Exhibition, New Orleans, LA, March 2008.
- **Student(s) Supported Under This Grant**
  - Brian Bates, Master student, Department of Mechanical Engineering, Tennessee Technological University
  - Yongqing Wang, Ph.D. student, Department of Mechanical Engineering, Tennessee Technological University, graduated in December, 2006